[redacted]

FACILITY FORM 602

N65 21718
(ACCESSION NUMBER)

50
(PAGES)

CR 62206
(NASA CR OR TMX OR AD NUMBER)

(THRU)

1
(CODE)

29
(CATEGORY)

ED PRELIMINARY DATA

GPO PRICE $ ______

OTS PRICE(S) $ ______

Hard copy (HC) 2.00

Microfiche (MF) .50

RADIO ASTRONOMY OBSERVATORY

DEPARTMENT OF PHYSICS

FLORIDA STATE UNIVERSITY

TALLAHASSEE, FLORIDA

031265

Status Report No. 6

Final Report on Grant NASA-NSG-224-61
and Supplement (1963)
to
National Aeronautics
and
Space Administration
from
Department of Physics
Florida State University
Radio Astronomy Programme

Period: August 1, 1964 through January 31, 1965

Submitted by

C. H. Barrow

Principal Investigator

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

ABSTRACT

21712 over

Radio observations of Jupiter have been in progress at all of the various stations operated by the Florida State University Radio Observatory throughout most of the period of the present report. Further polarization observations have been made at Tallahassee and these are still in progress. A complete series of 18 mc/s observations has been collected from the north-south line of five stations and analysis of the data is in progress.

The study of Solar-Jupiter relationships has been continued and there is evidence of a possible correlation between major Jupiter events and Solar M-region storms.

Further statistics on the 1963 polarization observations have been compared with the predictions of the Doppler-Shifted Cyclotron Theory.

Editing has begun of data taken during the period 1961 to 1963, prior to microfilming of records for the NASA Space Science Data Center. A catalog of Jupiter activity is to be prepared as a by-product of this work.

Future plans are outlined for a spaced-site experiment to study the influence of the Earth's ionosphere upon the polarization of the Jupiter radiation at 18 mc/s. All four polarization parameters are to be measured during the next two apparitions.

→ over

A review is presented of all of the research conducted during the entire three year period of the grant and supplement. The work is described in context with related studies conducted by other workers.

I. SIX MONTH PERIOD AUGUST 1, 1964 THROUGH JANUARY 31, 1965

1. Observations

(i). Tallahassee

Further observations of polarization have been made at 16, 18, 22 and 26 mc/s throughout the entire period of the report. These are continuing at the time of writing.

The observatory was struck by lightning during a storm in August, 1964 and this caused damage to some of the receivers and associated switching circuitry. Most of the damage was repaired fairly quickly and observation continued with a relatively short break. However, a receiver fault which developed subsequently may have originated in lightning damage and this further put one channel out of action for two weeks. Repairs have been covered by insurance.

(ii). Overseas Stations.

Coordinated observations have been made at 18 mc/s during the period August 1 through December 15, 1964. The five stations lie along a rough north-south line and their locations are shown in Figure 1. Complete sets of data have been received from all of these stations, and a first analysis has just begun. There are several remarkable instances where an event is reported by three or four stations and identification between these stations is in agreement to within a minute or two. At the same time however, the remaining stations report no evidence of activity. Some examples of this are shown in Table 3. It is proposed to compare such events with magneto-ionospheric characteristics at the time of observation.

2. Analysis Programs

(i). Doppler-Shifted Cyclotron Theory

In a previous report (No. 4) the Principal Investigator presented a comparison of experimental polarization data taken in 1963 with some of the predictions of the Ellis and McCulloch Theory (11). Some further statistics have been added to this comparison and these are included in the review section of the report (see Figure 7). The summed axial ratio has been plotted against the number of bursts and the distribution is found to be roughly linear but with a fairly wide scatter of points.

(ii). Solar-Jupiter Relationships

As described in previous reports a first attempt to find a correlation between solar activity and Jupiter activity consisted of a simple cross-correlation study between Jupiter activity (recorded at Tallahassee during 1961 and 1962 and at three separated stations during the 1963 apparition) and various indicators of solar activity. In general agreement with other workers the results were inconclusive and it was pointed out in the published account (16) of the preliminary study that this was hardly surprising due to over-simplification of the problem and certainly did not exclude the possibility of a more complex relationship between the phenomena. Following a suggestion by Carr et al (2) and using Jupiter data obtained at Tallahassee in 1961 and also published data from listings by Warwick and Kreiss (17) and by Douglas and Smith (18), Mr. G. M. Resch has considered the possibility of strong Jupiter storms being associated with solar M-region storms. These storms are not associated with visible solar flares, but are long lasting, often for several rotations, and it is believed that the emitted particle streams sweep through interplanetary space like spokes on a wheel. The analysis consists of identifying the M-region storms and from their speed of rotation and the angular distance between the Earth and Jupiter predicting a time for interaction of the associated particle streams with the Jovian magnetosphere. Using the facilities kindly accorded to us by the NASA Space Data Center at Greenbelt, Maryland, Mr. Resch has made a preliminary analysis for 1961 and this is summarized in Table 1. It can be seen that for the major Jupiter events considered the agreement between predicted and observed activity is good. It remains to be seen whether such good agreement persists over longer periods of observation.

3. Arrangements for Supplying Data to NASA Space Science Data Center

Mr. D. Morrow has been appointed to take charge of editing and preparing data for microfilming for the NASA Space Science Data Center. During the course of this work a catalog is to be prepared of all Jupiter activity observed at Florida State University Radio Observatory and its outstations since 1961. A special computer program has been written for compiling this catalog. This program gives a print-out of periods of observation and activity in Universal Time and Central Meridian longitude, also a smoothed histogram of each series of observations.

4. Publications August 1, 1964 through January 1, 1965

"Recent Radio Observations of Jupiter", Barrow, C. H., J. Brit. Ast. Assn., (In press).

"Preliminary Results of Spaced-Site Observations of Jupiter in 1963", Barrow, C. H., Resch, G. M., Hyde, F. W., Gruber, G. M., Bosch, M. C. Nature, 204, 637 (1964).

"A Spaced-Site Experiment to Search for Possible Correlations between Decameter-Wave Radiation from Jupiter and Solar Activity", (abstract)
Barrow, C. H., Bull. Am. Phys. Soc., Series II, 10, 249 (1965).

1964 Astronomical Yearbook, (Eyre and Spottswoode, London, 1964)
Chapter entitled "The Radio Sun", Hyde, F. W.

"Spaced-Site Observations of Jupiter", Hyde, F. W. J. Brit. Ast. Assn., (In press).

Talks given during the period:

C. H. Barrow

"A Spaced-Site Experiment to Search for Possible Correlations between Decameter-Wave Radiation from Jupiter and Solar Activity",
S.E.A.P.S. Meeting, Chattanooga, Tennessee (November 5, 1964)

F. W. Hyde

Colloquia and Seminars:-

Queen Mary College, University of London.

Oxford University Astronomical Society.

Radio Society of Great Britain.

Mr. F. W. Hyde attended the 12th IAU Meeting in Hamburg as an official representative of the British Astronomical Association.

5. Personnel Working on the Grant:

(a) Tallahassee

C. H. Barrow, Assistant Professor and Principal Investigator

D. Morrow, Graduate Assistant

G. M. Resch, Graduate Assistant

J. H. Cocke, Electronics Technician

G. R. Adcock, Undergraduate Assistant

K. Peale, Undergraduate Assistant

J. Merrit, Undergraduate Assistant

*R. Bukovitz, Undergraduate Assistant

N. Hazelwood, Undergraduate Assistant

*Terminated during the period.

(b) St. Osyth

F. W. Hyde, Radio Engineer and Director of St. Osyth station (Self supported).

D. Crosswell, Part-time Secretary

Personnel Associated with the Project:

(a) Grahamstown, South Africa

E. E. Baart, Lecturer in Physics and Director of Radio Astronomy

M. C. Bosch, Graduate Assistant

G. M. Gruber, Graduate Assistant

(b) Local supervisors for the 1964 spaced-site observations.

R. W. Morriss, Lecturer in Physics, University of Ibadan

J. Catala, Professor of Physics, University of Valencia

H. Torgerson, Engineer, Technical University of Trondheim

Groups of from 3 to 5 undergraduate assistants were employed on the Grant at St. Osyth, Ibadan, Valencia, and Trondheim during the period August 1 through December 15, 1964.

II. ENTIRE PERIOD OF GRANTS, FEBRUARY 1, 1962 THROUGH JANUARY 31, 1965

1. Review of Research

(i). Introduction

Radio studies of Jupiter have been in progress at Florida State University since 1960. The first year of this work was financed by the University Research Council, but from February 1, 1962, through January 31, 1965, the radio astronomy program has been sponsored by the National Aeronautics and Space Administration (Grant NsG-224-61 and Supplement).

During the last two years the program has grown considerably and effort has been concentrated on three related aspects, polarization studies and spaced-site experiments to study the influence of the Sun and of the Earth's ionosphere on the decameter-wave radiation from Jupiter.

In the following sections the work conducted during the past three years is reviewed in the context of related observations by other workers.

(ii). Polarization

The polarization of the decameter-wave radiation from Jupiter was first studied by Franklin and Burke (1), and by Carr et al. (2). Both groups found that at 22 mc/s most of the noise bursts were right-handed elliptically polarized (R.H.) in the radio convention of looking along the direction of propagation. A single observation by

Gardner and Shain (3) showed a similar result at 19.6 mc/s. As R.H. polarization had been observed at stations in both the northern and southern hemispheres it was concluded that this polarization was due to conditions on Jupiter and was not an effect of the terrestrial ionosphere. During the 1961 apparition, however, a few observations by Barrow (4), at 18.3 and 24 mc/s, suggested that a smaller proportion of R.H. bursts were to be found at 18.3 mc/s than at 24 mc/s. The following year several observers found variations in the polarization at lower frequencies. According to Carr (5) a number of bursts recorded at 16 mc/s showed L.H. polarization whereas at 22 mc/s the bursts were almost exclusively R.H. Barrow (6) also observed L.H. polarized bursts at 16 mc/s. Dowden (7), working at 10.1 mc/s found that not only were some of the bursts L.H. but also, that the variations in polarization mode appeared to be correlated with the Jupiter System III central meridian longitude. Sherrill and Castles (8), using a system which could be tuned manually to successive different frequencies in the range 15 to 24 mc/s, observed varying proportions of L.H. bursts at frequencies below 22 mc/s.

During the 1963 apparition a series of observations were conducted at Florida State University at 16, 18, 22, and 26 mc/s using the switching system shown schematically in Figure 2. From these observations (Barrow (9)) appeared the important result that most of the radiation at 22 and

26 mc/s was R.H. polarized whereas at 16 and 18 mc/s an appreciable proportion of bursts were L.H. In particular, of all the bursts observed when $300° < \lambda_{III} \leq 360°$ (λ_{III} is the central meridian longitude of the planet corresponding to the I.A.U. recommended radio rotation period for Jupiter) as many as 41% and 30% were found to be, respectively, L.H. at 16 and 18 mc/s. The general characteristics are summarized in Table 2. From these results and from those of Sherrill and Castles (8) and of Dowden (7) it appears that the amount of L.H. polarization observed increases towards the lower frequencies. Agreement is good as far as this aspect of the observations is concerned. There is less agreement concerning the possibility of a relationship between the sense of polarization and central meridian longitude of Jupiter. Both Dowden and Barrow found some evidence of a relationship at their respective working frequencies. Sherrill (10), however, does not find any clear relation in his 1963 data although his 1962 data showed slight indications of a correlation. Unambiguous comparison is not easy, however, because of the different techniques and different frequencies involved. If a permanent relationship were to be supported by the statistics of several years this would offer another approach to the important problem of deducing the form of Jupiter's magnetic field. Sherrill (10), attempted to measure the degree of polarization during 1963 and found evidence of a number of linearly polar-

ized bursts on several occasions. All other published observations have been confined to comparison of R.H. and L.H. components.*

By this latter technique, Barrow (4), (9), also found evidence of random-linear bursts, notably at 18 mc/s, corresponding to those identified by Sherrill. The system used did not permit a distinction to be made between random and linear polarization however.

Further observations have been made during the 1964 apparition and these are still in progress. An improvisation has been made recently to attempt to measure the degree of polarization at 18 mc/s by comparing the elliptical component with the total intensity; a really satisfactory event for analysis has yet to be recorded, however.

(iii). Comparison of Polarization Observations with the Predictions of the Doppler-Shifted Cyclotron Theory

A theory has been proposed by Ellis and McCulloch (11) in which the decametric radiation from Jupiter is attributed to cyclotron radiation emitted by bunches of electrons accelerated as a result of disturbances occurring near the boundary of a postulated Jovian exosphere. The electrons travel in helical paths along high latitude magnetic field lines and in so doing they emit electromagnetic

*Faraday rotation in the Earth's ionosphere is large at these frequencies and complicates the measurements. The effect is greater when Jupiter is seen at low elevation angles. This has been the case until recently when Jupiter moved to a northerly declination.

radiation. The general picture corresponds with what is known of terrestrial VLF emission but with the condition that only electrons with velocity components sufficiently great to produce a Doppler shift of forward emitted radiation to a value greater then the extraordinary-wave critical frequency can escape, either directly (outward travelling bunches) or after reflection (inward travelling bunches).

Using 1963 data, axial ratios have been computed for each burst, assuming complete polarization, and an analysis, similar to that made for 10.1 mc/s observations by Dowden (7), has been made, so that the results may be compared with the Ellis and McCulloch theory. This is illustrated in Figures 3-7. The two lower frequencies are of greatest interest as it is at 16 and 18 mc/s that appreciable proportions of L.H. polarized bursts have been observed. Also, there are more bursts available for analysis (see Table 2) at these frequencies. The 22 and 26 mc/s computations have been made for the sake of completeness but they do not contribute anything very conclusive to the discussion and are not included in the Figures 3,5 and 6.

In Figure 3 the distributions of axial ratios are compared with the observations of Dowden (7). The 18 mc/s results, in particular, are in good agreement with the distribution predicted by the Ellis and McCulloch theory (shown in Figure 4) and the 16 mc/s results are reconcilable if we accept Dowden's suggestion that the lower axial ratios are produced by superimposed bursts of higher axial ratio but opposite sense. It is the shape of the distribution which is significant. The position on the axial ratio scale depends upon the assumed model of Jupiter rather than on the theory.

In Figure 5 the smoothed occurrence rates of L.H. and R.H. bursts are compared. In Figure 6 the smoothed longitude variation of burst occurrence is shown. According to Dowden's results this latter may also be regarded as an indication of the distribution of total power radiated. In Figure 7 the summed axial ratio is plotted against the number of bursts and compared to an arbitrary straight line of slope 1.05 (predicted for the atmospheric model assumed by Ellis and McCulloch). The distribution of the points is found to be roughly linear but with a fairly wide scatter.

The Ellis and McCulloch theory seeks to explain the experimentally observed longitude profiles of occurrence probability and power distribution. A suitable choice of magnetic field anomaly, expressed as a dip anomaly, readily produces the differing profiles observed at 5 and 10 mc/s compared to those found at higher frequencies. Thus histograms of the type shown in Figure 8 as well as the burst distribution (Figure 6) are, by definition, consistent with the theory. The axial ratio distributions shown in Figure 3, particularly at 18 mc/s, are in good agreement with the predictions of the theory and are at present the most significant experimental evidence in its favor.

In view of the already established results explained by the theory as well as the polarimeter data, it is felt that this theory may offer the most satisfactory explanation of the origin and escape of the decametric radiation to date. It is perhaps significant that, unlike most theories that have been proposed, the Doppler-shifted cyclotron theory seeks to explain the radiation in terms of characteristics which are known to occur on a different scale within the atmosphere of the Earth. It will be interesting to see if the satellites proposed for studying VLF emission from the Earth find evidence of any longitude profile of radiated power due to the Earth's magnetic field.* However, the recent work of Bigg (12), who finds good evidence of a correlation between the motion of the Jupiter satellite Io and periods of Jupiter activity, may, if confirmed, necessitate a drastic revision of some contemporary ideas on the origin of the radiation. It is proposed to examine the Jupiter data taken at Florida State University for evidence of the Io correlation.

(iv). <u>Possible Influence of the Sun on the Jupiter Radiation</u>

*Information on this point is not yet available. The Principal Investigator has been in communication with Professor R. A. Helliwell, Stanford University, concerning this possibility.

It has been suggested by several investigators that the radiation from Jupiter is in some manner related to solar activity, in that periods of Jupiter activity frequently follow periods of solar activity within a few days.* This effect was first reported by Warwick (13) and has also been observed by Carr et al. (2), by Douglas (14), and by Barrow (4). There is, however, no general agreement as to an average delay time between periods of solar activity and possible related periods of Jupiter activity, estimates of from two to ten days having been proposed by the various investigators.

Roberts (15), using data obtained in 1960 by Carr et al. (2), computed the correlation coefficient between Jupiter activity and the geomagnetic activity index A_p. A peak corresponding to a delay of eight days was indicated but at the same time another peak of comparable significance indicated a negative delay of eight days, that is, for geomagnetic activity after Jupiter activity. Roberts mentions similarly inconclusive unpublished results obtained by Higgins and concludes that all the apparent correlations observed so far may be merely statistical fluctuations.

If the phenomena are in fact related, there are two possible explanations of these different results. Either the statistics are unsound due to the fact that insufficient

*An inverse correlation with the sunspot cycle has also been claimed by some investigators. This cannot be unambiguously established however, as the revolution period of Jupiter (11.9 years) is almost in phase with the sunspot cycle.

Jupiter observing time was available daily for comparison with solar activity, or else the relationship between the two phenomena is too complex to be expressed by a simple cause and effect explanation. A preliminary investigation of the former possibility was conducted during 1963 by Florida State University Radio Observatory in collaboration with observatories in England and in South Africa, (Barrow et al. (16)).

The experiment was simply to record the radiation from Jupiter for as long as possible each day and to compare the periods of Jupiter activity with periods of solar activity as indicated by flares, 10 cm. solar radiation, sunspots, and geomagnetic activity. The sun can be observed from somewhere on the Earth almost 24 hours daily whereas most Jupiter observers are limited to some four to eight hours according to their antenna systems. The daily period of observation of Jupiter was, therefore, increased to some extent by combining observations made at two additional sites; at St. Osyth, England, and at Rhodes University, Grahamstown, South Africa, with data taken at Tallahassee. The combined observations from the three stations operating in tandem amounted to some 16 hours continuous monitoring each night, a period corresponding to about 1½ rotations of Jupiter.

It is emphasized here, as in the relative supplemental proposal, that this experiment was essentially a utilization of existing facilities at established observatories. The locations of the participating stations were satisfactory but not ideal. It was suggested that the project might be regarded as an inexpensive pilot experiment to see whether or not a more elaborate network of sites might be a worthwhile project for the future as a means of monitoring Jupiter 24 hours daily. Analysis of the data from these observations is still in progress but the following can be stated at the present time. A first examination (Barrow et al. (16)) was made by computing correlation coefficients between Jupiter activity and several indicators of solar activity. No correlation appeared which could not equally well be regarded as statistical fluctuation. Thus it appears so far, that increased daily observation of Jupiter does not, by itself, produce any significant improvement in a search for simple cross-correlation. This result does not, however, exclude the possibility of any relationship at all between Jupiter activity and solar activity as there are various factors which might obscure a simple correlation study. For example, if Jupiter activity is initiated in any manner by solar corpuscles, as Carr et al. (2) have suggested, both the magnitude and the direction of the velocity of the corpuscles would have a bearing on the situation. Particles travelling with different velocities on different days would give rise to different delay times and a direct search for cross-correlation would be useless.

A detailed study of the data is now being made by Mr. G. M. Resch to examine the second possibility (above) further. Using a combination of data obtained at Tallahassee with that published by Warwick and Kreiss (17) and by Douglas and Smith (18) for 1961, following a suggestion by Carr et al. (2), Resch finds evidence of an association of strong Jupiter storms with solar M-region storms. The results to date are summarized in Table 1.

(v). <u>Influence of the Earth's Ionosphere on the Radiation</u>

Evidence continues to appear of terrestrial ionospheric effects in the Jupiter radiation. Smith, A. G. et al. (19) compared high-speed recordings taken simultaneously in Florida and in Chile (7,000 km baseline) and found that in some cases there was good burst-for-burst correlation, in some cases there was no correlation and in some cases there was burst correlation with a phase difference of about 10 seconds. Using shorter baselines (15 to 100 km), in the vicinity of Yale University, Douglas and Smith (20) found considerable correlation between very high speed recordings taken from four sites. They interpreted this as indicating an intrinsic fine structure to the radiation independent of any effect which the Earth's ionsophere might impose. More recently, Douglas (21) has identified and classified four different types of Jupiter burst, essentially on their time durations. Very short term characteristics are regarded as primarily of terrestrial origin and longer bursts are regarded as truly Jovian in origin.

An interesting feature of the 1963 Florida State University spaced-site observations is the pronounced difference in Jupiter activity recorded at each site. The day-by-day frequency of occurrence was found to be considerably higher at Tallahassee than at St. Osyth and considerable higher at Grahamstown than at Tallahassee. Such differences have also been reported by Carr (22) for observations made at Gainesville, Florida; at Santiago, Chile; and at Sydney, Australia.

During 1964, coordinated observations were made at 18 mc/s from five stations along a rough north-south line for a period of 4½ months. The locations of the stations are shown in Figure 1. A comparison of the data taken simultaneously at each station is now in progress. There are a number of occasions where an event is reported by three or four stations and identification between the stations is in agreement to within a few minutes. At the same time there may be one intermediate station that finds no evidence of any activity even when it has been identified by groups as far apart as Trondheim, Norway and Grahamstown, South Africa. Some examples are shown in Table 3. It can be seen that on October 5 all stations reported Jupiter activity whereas on October 24 the first event was reported by three stations and the second by four stations. No evidence of activity was found at Ibadan. Similarly on August 24 two events were reported by three of the four stations observing while no evidence of activity was found at St. Osyth. Even allowing for a certain amount of subjectivity in the aural monitoring identification procedure occurrences such as these can hardly be coincidental. Careful examination is to be given to this data in the light of reported ionospheric conditions at the times of observation.

Very recently, Warwick and Dulk (23) have presented evidence of Faraday rotation of the Jupiter radiation in the Earth's ionosphere. They suggested that the Jupiter radiation may be rotated in the Earth's ionosphere but not in the ionosphere of Jupiter if it is generated in a single magnetoionic mode as some current theories suggest (Warwick (24)). Thus, when suitable measurements are available, it may be possible to extrapolate ellipse orientations observed on the Earth back to Jupiter, provided that the large amount of Faraday rotation occurring at decameter-wave frequencies can be maasured or calculated to a sufficient degree of accuracy.

2. Future Plans

Continued support has been granted for an experiment to study the polarization of radiation from Jupiter in more detail and with greater precision than in the past. All four polarization parameters are to be measured at 18 mc/s and by using three separated, crossed arrays the effect of the Earth's ionosphere on the noise bursts will be studied in detail. The next two years are particularly favorable for this study as Jupiter will appear at Tallahassee close to the zenith at meridian transit. Identification is to be made more conclusive than before as in addition to monitoring this will be based on a comparison of records taken at each separate antenna as well as on a phase-switched interferometric arrangement between one array and a subsidiary antenna. In addition L.H. and R.H. components will be compared at some lower frequency close to 12.5 mc/s. Faraday rotation disperses the polarization ellipses within the bandwidth of the receiver and makes the measurement of the other polarization parameters unreliable at such a low frequency.

Using the north-south line of overseas stations another series of coordinated observations will be taken at 18 mc/s with the additional refinement of a high speed recorder at each station. This will enable the structure of individual bursts to be compared from one site to another. Only lack of funds prevented the installation of this equipment during the previous year.

Thus two of the main interests of previous years will be brought together in the future and the influence of the

Earth's ionosphere, not only on the general radiation from Jupiter but also on the form of the polarization will be studied. Noise bursts which show the same polarization characteristics at each of the separated sites can thus be regarded as owing their characteristics entirely to conditions on Jupiter rather than conditions on the Earth. Two of the sites are to be located in Tallahassee separated by a short base line of a few miles. This separation is sufficient to reveal differences due to ionospheric drifts and irregularities which travel relatively slowly with velocities of the order of 100 m/s. The third polarimeter will be located at the University of the West Indies at Jamaica, some 1,100 miles south of Tallahassee (Figure 9). Large scale differences in ionospheric effects on the radiation should thus be detected by comparison of observations made at this station with the observations taken at Tallahassee. Three Cohen-type polarimeters (25) (see Figure 10) are being manufactured by Aero-Space Research Inc. for this project. Observations will continue with existing equipment at 26, 22, 18 and 16 mc/s.

The future research program will attempt to introduce a higher degree of precision in the observational procedures and to answer some of the questions raised by the previous work. Due consideration has been given to recent developments by other workers in the field and the emphasis is to be placed upon aspects which are receiving the least attention elsewhere. The main objectives may be summarized as follows:

1. To investigate further the polarization of the radiation at frequencies below 20 mc/s and to measure all four polarization parameters at 18 mc/s.

2. To see if a permanent relationship exists between the sense of polarization and the System III central meridian longitude of Jupiter.

3. To study the effect of the Earth's ionosphere on the radiation and the polarization by the following observations made simultaneously from separated sites.*

(a). Comparison of day-by-day frequency of occurrence.

(b). Comparison of burst structures observed with accurately timed high-speed recorders.

(c). Comparison of radiation intensity.

(d). Comparison of polarization records.

4. Further to compare the polarization results with the predictions of theory, notably the Doppler-Shifted Cyclotron Theory of Ellis and McCulloch (11), but with due regard to the work of Bigg (12) concerning the possible influence of the Jovian satellite Io.

5. Interest in the possibility of solar correlation effects will continue, but largely on an analytical basis.

*It is emphasized that the purpose is to study the effect of the ionosphere on the Jupiter radiation rather than the ionosphere itself. This latter can obviously be studied more effectively by other methods.

The radio astronomy group at NASA, Greenbelt, are now coordinating a daily 24 hour watch on Jupiter by use of the Minitrack systems around the world. An extension of this aspect of the experimental program by Florida State University would appear to be superfluous.

LIST OF REFERENCES

1. Franklin, K. L., and Burke, B. F., J. Geophys. Res., 63, 807 (1958).
2. Carr, T. D., Smith, A. G., Bollhagen, H., Six, F., Chatterton, N. E., Astrophys. J., 134, 105 (1961).
3. Gardner, F. F. and Shain, C. A., Aust. J. Phys., 11, 55 (1958).
4. Barrow, C. H., Astrophys. J., 135, 847 (1962).
5. Carr, T. D., NASA Jupiter Conference, New York, October, 1962.
6. Barrow, C. H., Nature, 201, 171 (1964).
7. Dowden, R. L., Aust. J. Phys., 16, 398 (1963).
8. Sherrill, W. M. and Castles, M. P., Astrophys. J., 138, 587 (1963).
9. Barrow, C. H., Icarus, 3, 77 (1964).
10. Sherrill, W. M., Southwest Research Institute Report, Project No. 06-1358IR, 1964.
11. Ellis, G. R. A., and McCulloch, P. M., Aust. J. Phys., 16, 380 (1963).
12. Bigg, K. E., Nature, 203, 1008 (1964).
13. Warwick, J. W., Science, 132, 1250 (1960).
14. Douglas, J. N., Yale University Thesis, (1960).
15. Roberts, J. A., Planetary and Space Sc., 11, 221 (1963).
16. Barrow, C. H., Resch, G. M., Hyde, F. W., Gruber, G. M., Bosch, M. C., Nature, 204, 637 (1964).
17. Warwick, J. W., and Kreiss, W. T., IGY Solar Activity Report Series, No. 28, November 2, 1964.
18. Douglas, J. N., and Smith, H. J., Astron. J., 68, 163 (1963).
19. Smith, A. G., Carr, T. D., Bollhagen, H., Chatterton, N., Six, F., Nature, 187, 568 (1960).
20. Douglas, J. N. and Smith, H. J., Nature, 192, 741 (1961).

21. Douglas, J. N., Trans. A.G.U., 44, 887 (1963).

22. Carr, T. D., Florida Academy of Sciences Meeting, Winter Park, Florida; March, 1964.

23. Warwick, J. W. and Dulk, G. A., Science, 145, 380 (1964).

24. Warwick, J. W., Astrophys. J., 137, 41 (1963).

25. Cohen, M. H., Proc. I.R.E., 46, 172 (1958).

APPENDIX I

Identification Procedures

Identification procedures vary considerably from one group to another and so, it appears, do some of the average occurrence probabilities claimed. The gain of the antenna system used must have some bearing on this and also the location of some sites may be more favorable than others. Identification procedures at present in use by the various workers in the field include aural monitoring with broad beam antennas, identification from interferometer records which may have been partially monitored or completely unmonitored, and comparison of records taken at separated sites.

The following procedure has been used by the various stations operated by Florida State University.

All of the observations were made at night when interference is at a minimum. Every period of observation was monitored by an observer and identification was by the aural monitoring technique. To be regarded as radiation from Jupiter the signal had to satisfy the following common-sense criteria:

1. Jupiter must be within the reception beam of the antenna.

2. The general recorder must show a deflection clearly visible above the background noise.

3. The signal must have the characteristic "swishing"

sound of Jupiter radiation.

4. The signal must not tune out over a small bandwidth of about $\pm$ 0.25 mc/s. This is an important distinction between Jupiter and a distant station which can sometimes sound very similar.

5. The signal must not be identifiable as of terrestrial origin. Static pulses, car ignition, and power line radiation are the most common forms of interference and all of these have characteristic sounds quite different from Jupiter radiation. Additional checks using the beat frequency oscillator and the noise-limiting circuitry are also possible. Use of the beat frequency oscillator makes station identification more certain and experience has shown that most Jupiter radiation can be detected with the noise-limiter on while the terrestrial interference listed above is suppressed to a large extent.

These criteria were rigorously applied by all of the observers who made their assessment of each event at the time when it was recorded. The time duration of the event is entered on a data chart from which computer cards are prepared to produce histograms for the period of the observations. To the best of the writer's knowledge this procedure is unique insofar as it does not include a study of the general records at some time, perhaps several months later, as a means of assessing the starting and finishing times of the events. It is felt that this approach gives the most objective procedure possible with the equipment available. A histogram, such as that shown in Figure 8, is good confirmation that the activity observed is Jovian in origin.

It is the opinion of the writer and his colleagues that all observations should be monitored no matter what receiving technique is used.

APPENDIX II

Publications during the period of the Grants.

1. "Recent Radio Observations of Jupiter at Decameter Wavelengths", Barrow, C. H., Astrophys. J., 135, 847 (1962).

2. "Decameter-Wave Observations of Jupiter in 1961", (abstract) Barrow, C. H., Astron. J., 67, 111 (1962).

3. "38 Mc/s Radiation from Jupiter", Barrow, C. H., Nature, 197, 580 (1963).

4. "A Brief Survey of the Decametre-Wave Radiation from Jupiter", Barrow, C. H., J. Brit. Ast. Assn., 73, 42 (1963).

5. "Polarization Observations of Jupiter at Decametre Wavelengths", (abstract) Barrow, C. H., Proceedings of the 11th Astrophysical Symposium, Liege, 1962. La Physique des Planetes (Cointe-Sclessin, Belgium, 1963) p. 563.

6. "A Note on the Polarization of 16 Mc/s Radiation from Jupiter", Barrow, C. H., Nature, 201, 171 (1964).

7. "An Experiment to Study the Relationship between Radio Noise from Jupiter and Solar Activity", Barrow, C. H. and Hyde, F. W. J. Brit. Ast. Assn., 73, 327 (1963).

8. "Polarization Observations of Jupiter at Decameter-Wave Frequencies", (abstract) Barrow, C. H., Trans. A.G.U., 44, 887 (1963).

9. "Mysterious Radio Emissions from the Planet Jupiter", Hyde, F. W., New Scientist, 19, 432 (1963).

10. "Radio Astronomy", Hyde, F. W., J. Soc. Engr's., 14, 195-221 (1963).

11. Practical Amateur Astronomy, (Lutterworth Press, London, 1963) Chapter 19, pp. 222-234. Hyde, F. W.

12. "Polarization Observations of Jupiter at Decameter-Wavelengths", Barrow, C. H., Icarus, 3, 66 (1964).

13. "Decameter-Wave Observations of Jupiter in 1963", (abstract) Barrow, C. H., Bull. Am. Phys. Soc., Series II 9, 352 (1964).

14. "Recent Radio Observations of Jupiter", Barrow, C. H., J. Brit. Ast. Assn., (In press).

15. "Preliminary Results of Spaced-site Observations of Jupiter in 1963", Barrow, C. H., Resch, G. M., Hyde, F. W., Gruber, G. M., and Bosch, M. C., Nature, 204, 637 (1964).

16. "Spaced-site Observations of Jupiter", Hyde, F. W., J. Brit. Ast. Assn., (In press).

17. 1964 Astronomical Year Book, (Eyre and Spottiswoode, London, 1964) Chapter entitled "The Radio Sun", Hyde, F. W.

18. "A Spaced-site Experiment to Search for Possible Correlations Between Decameter-wave Radiation from Jupiter and Solar Activity", (abstract) Barrow, C. H., Bull. Am. Phys. Soc.

LIST OF FIGURES

LIST OF TABLES

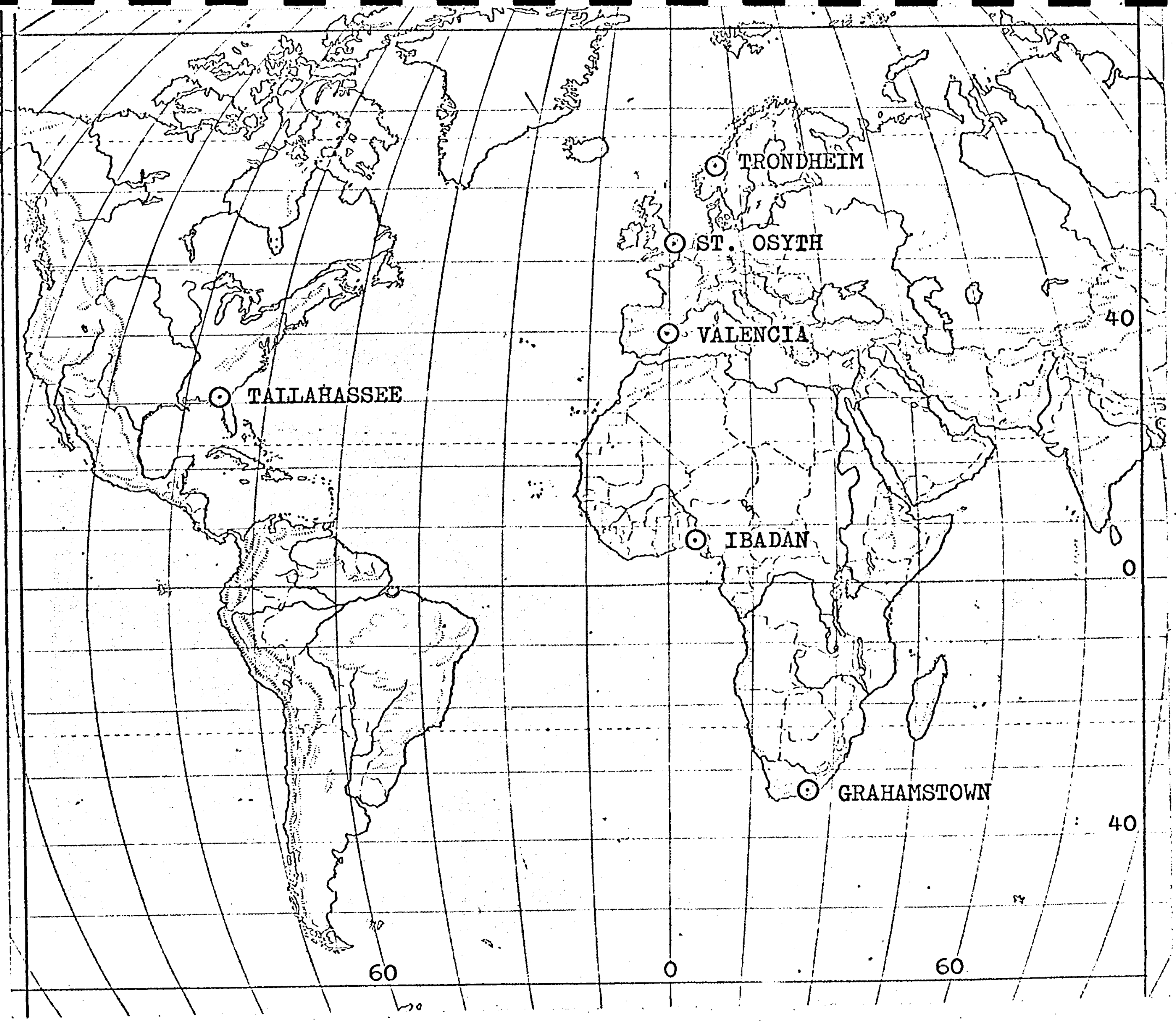

TRONDHEIM
ST. OSYTH
VALENCIA
TALLAHASSEE
IBADAN
GRAHAMSTOWN
40
0
40
60
0
60

Figure 1.

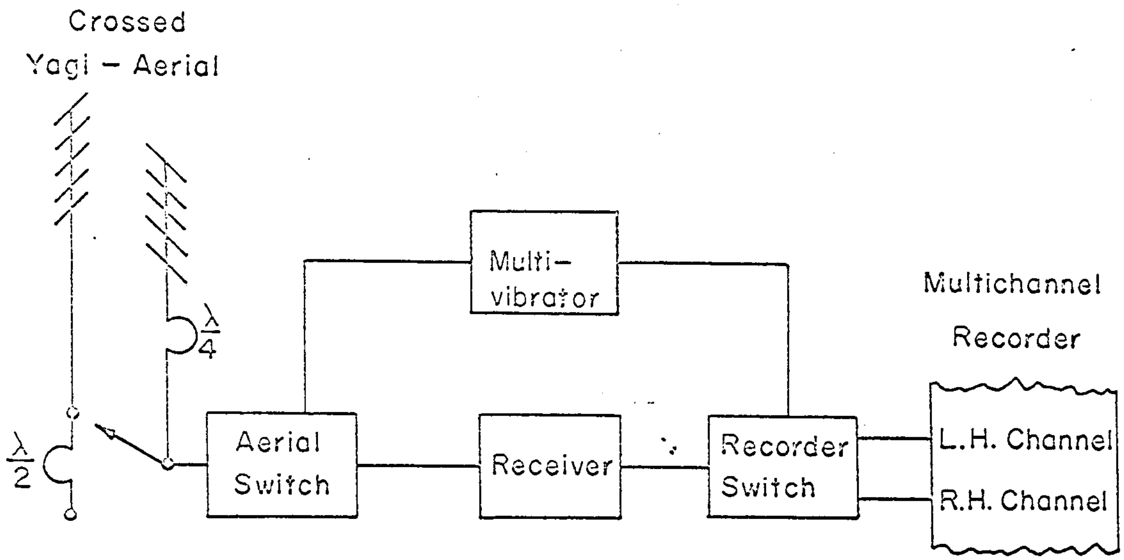

Crossed
Yagi - Aerial
$\frac{\lambda}{4}$
$\frac{\lambda}{2}$
Multi-
vibrator
Aerial
Switch
Receiver
Recorder
Switch
Multichannel
Recorder
L.H. Channel
R.H. Channel

Figure 2.

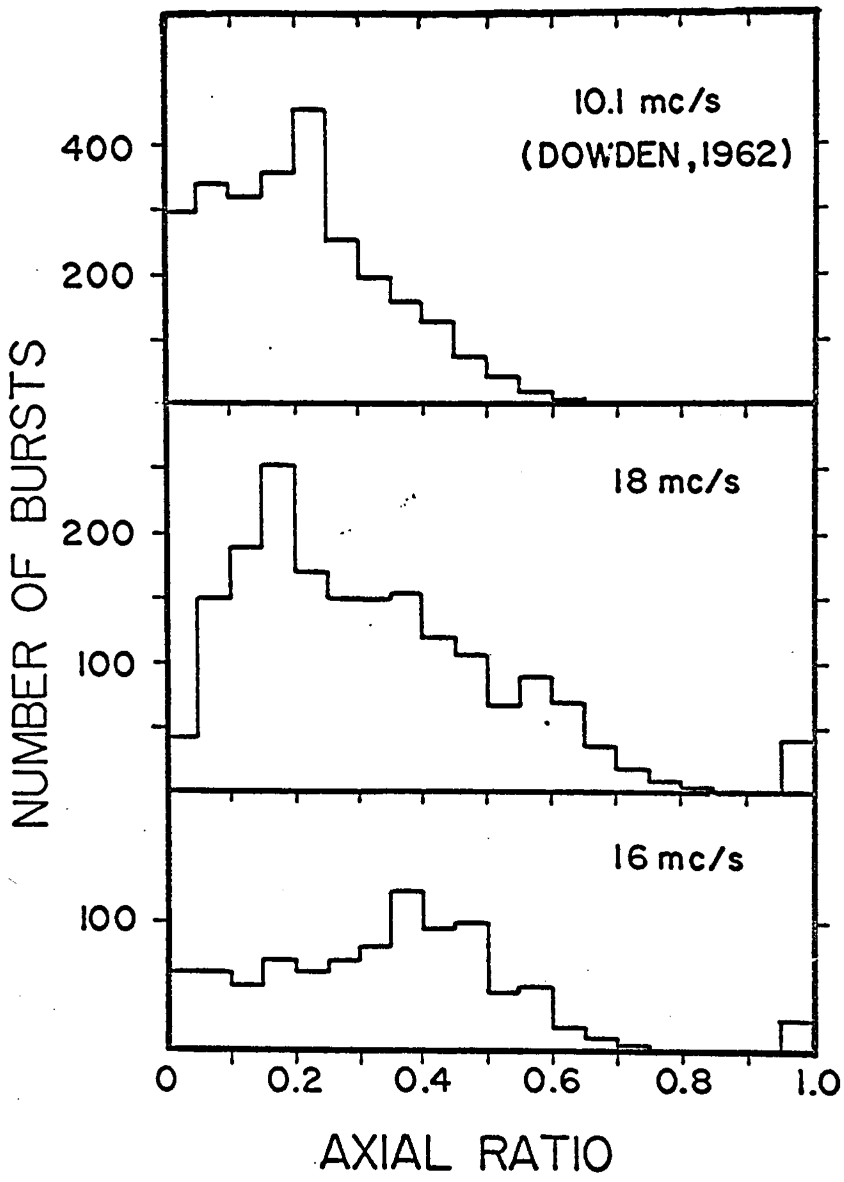

10.1 mc/s
(DOWDEN, 1962)
400
200
18 mc/s
200
100
16 mc/s
100
NUMBER OF BURSTS
0
0.2
0.4
0.6
0.8
1.0
AXIAL RATIO

Figure 3.

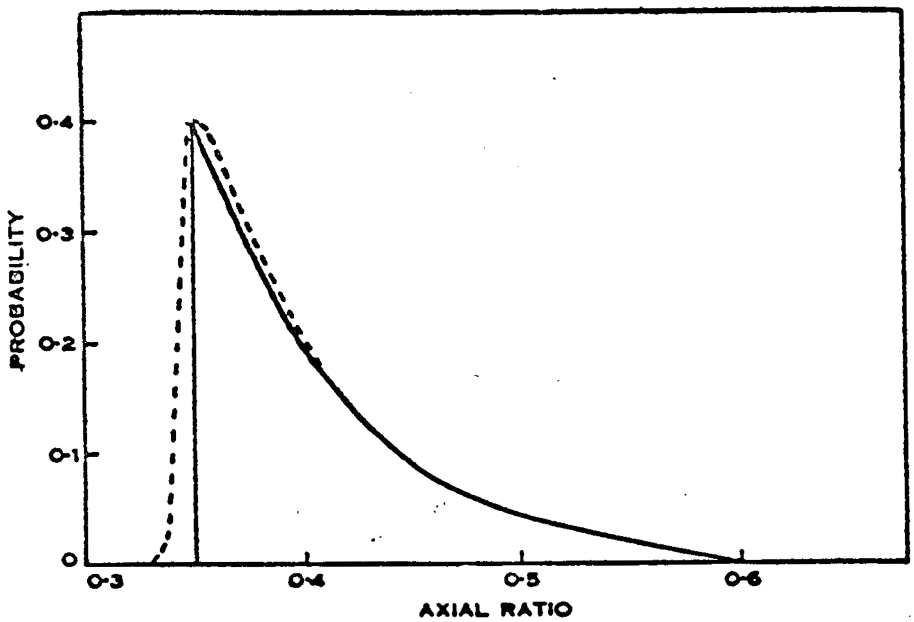
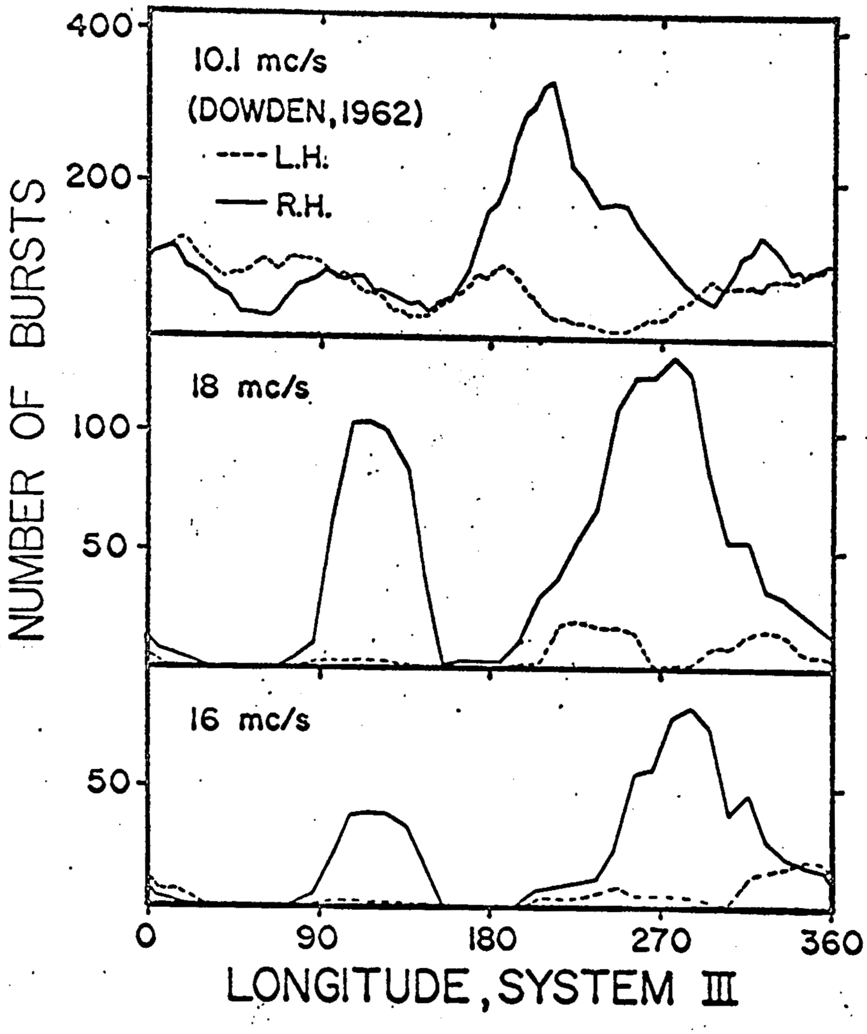


Figure 4.



NUMBER OF BURSTS
400
200
10.1 mc/s
(DOWDEN, 1962)
L.H.
R.H.
18 mc/s
100
50
16 mc/s
50
0
90
180
270
360
LONGITUDE, SYSTEM III

Figure 5.

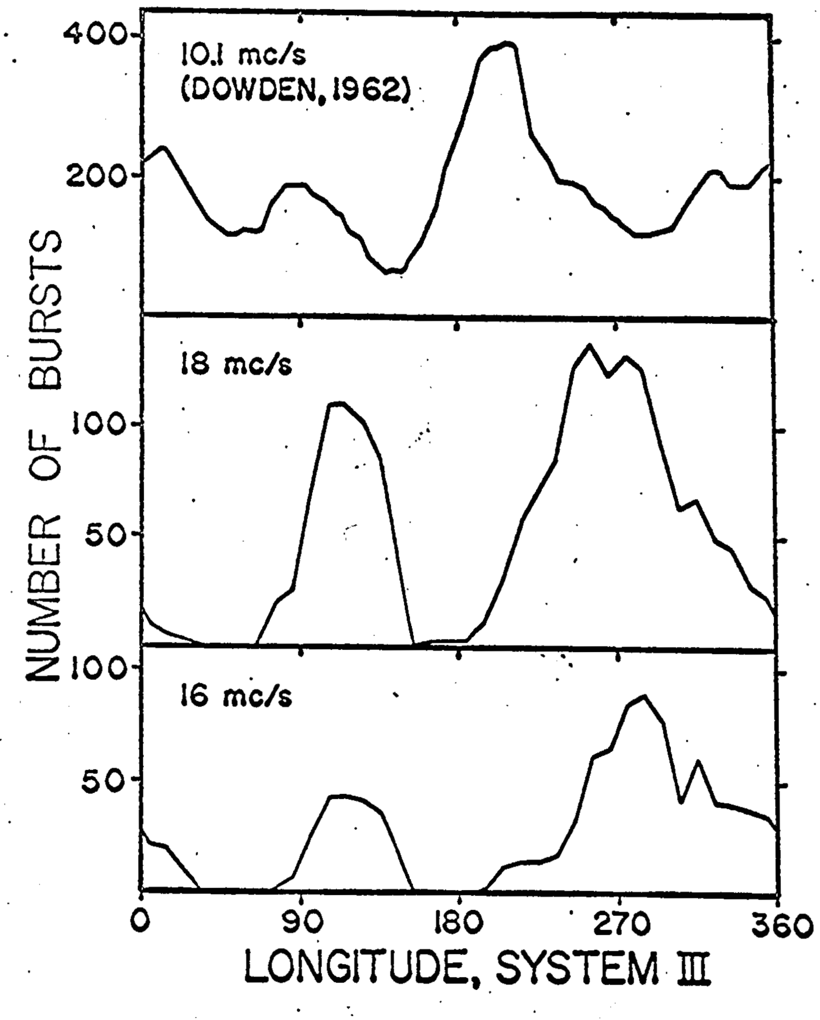
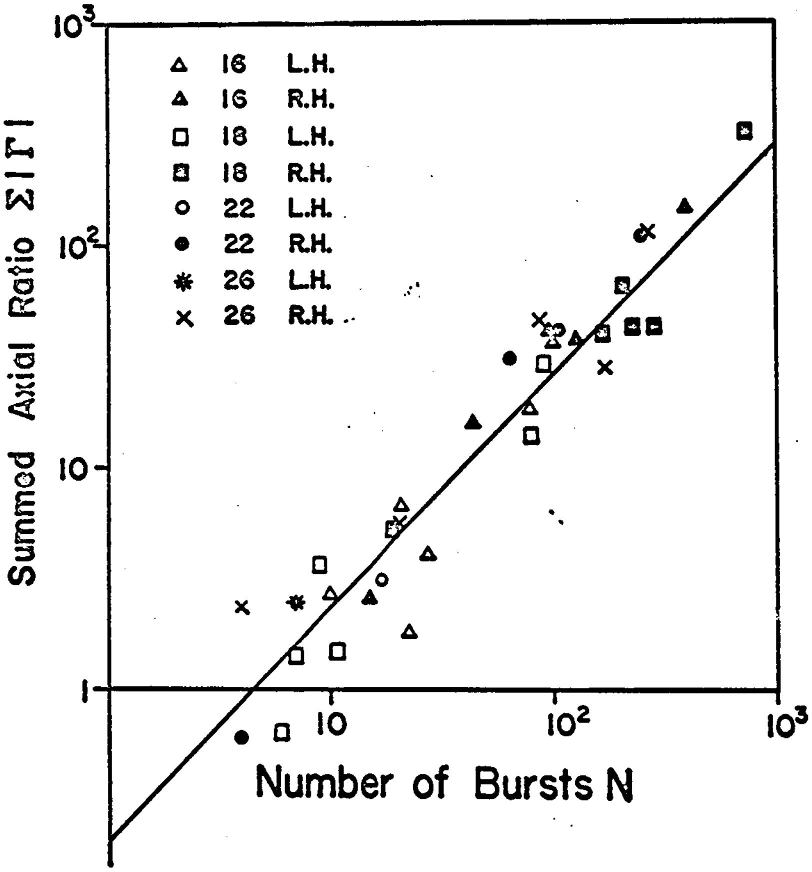
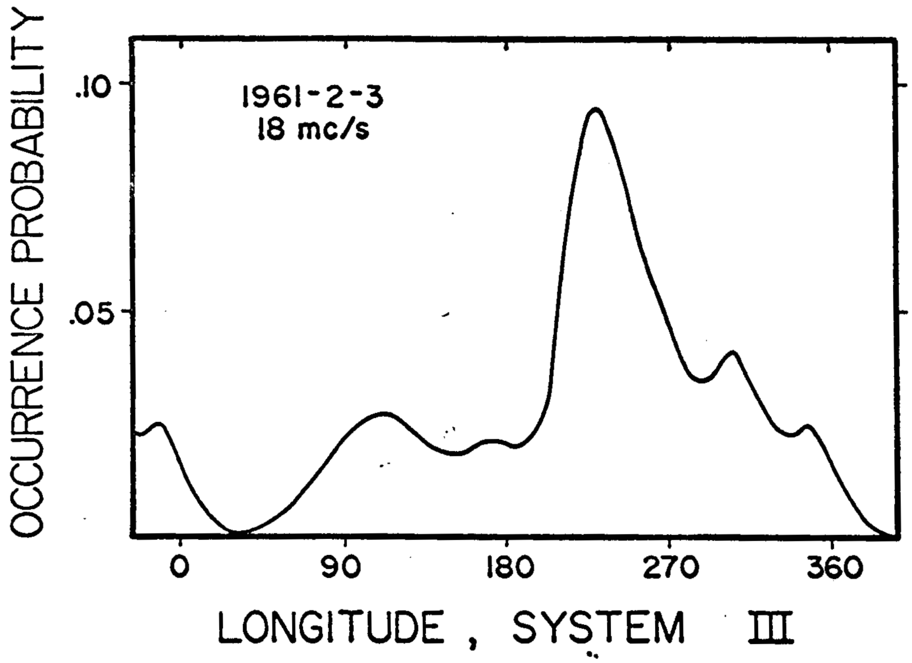

10.1 mc/s
(DOWDEN, 1962)
18 mc/s
16 mc/s
NUMBER OF BURSTS
400
200
100
50
100
50
0
90
180
270
360
LONGITUDE, SYSTEM III

Figure 6.



16 L.H.
16 R.H.
18 L.H.
18 R.H.
22 L.H.
22 R.H.
26 L.H.
26 R.H.
Summed Axial Ratio Σ|Γ|
Number of Bursts N
10³
10²
10
1
10
10²
10³

Figure 7.



OCCURRENCE PROBABILITY
.10
.05
1961-2-3
18 mc/s
0
90
180
270
360
LONGITUDE , SYSTEM III

Figure 8.

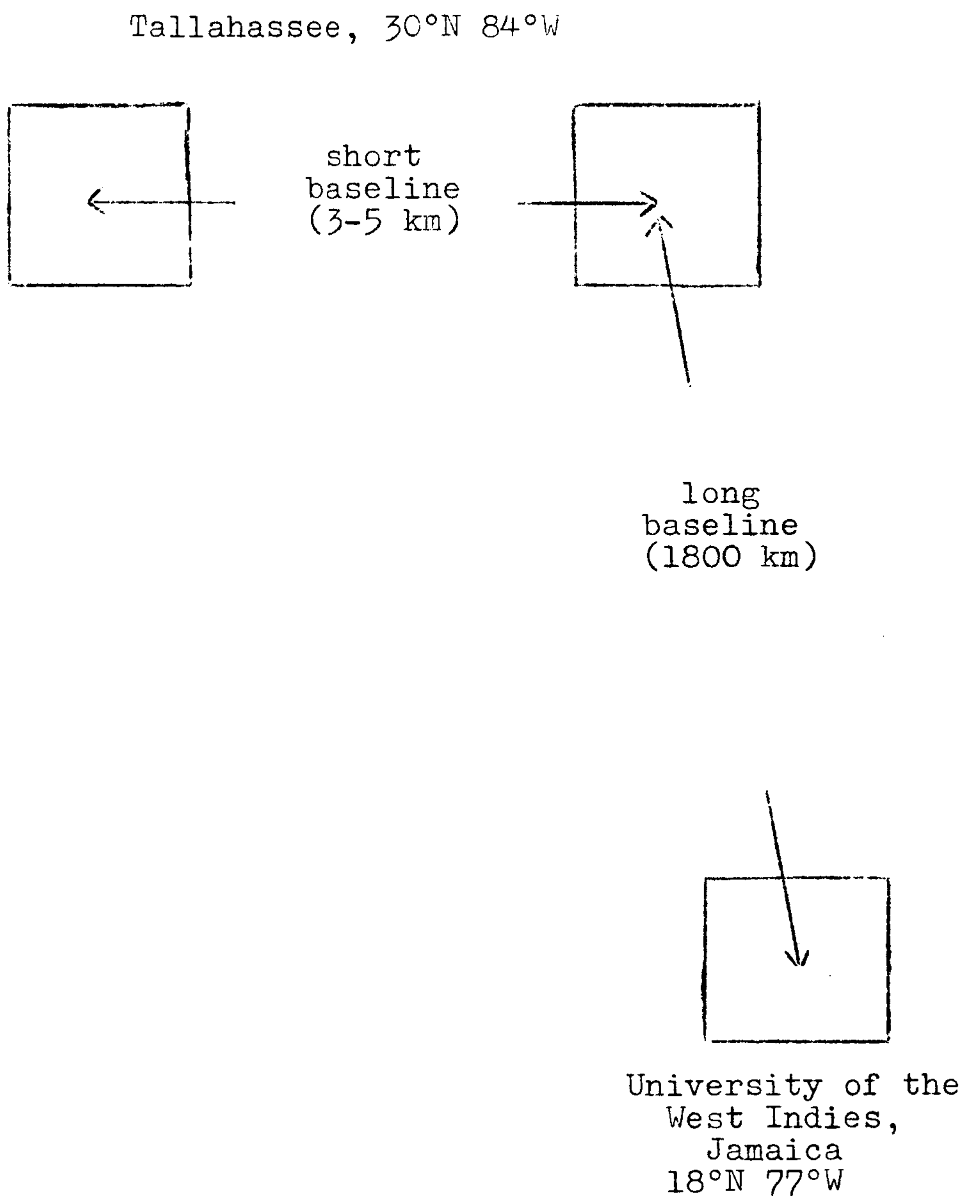


Figure 9. Arrangement of the polarimeter arrays.

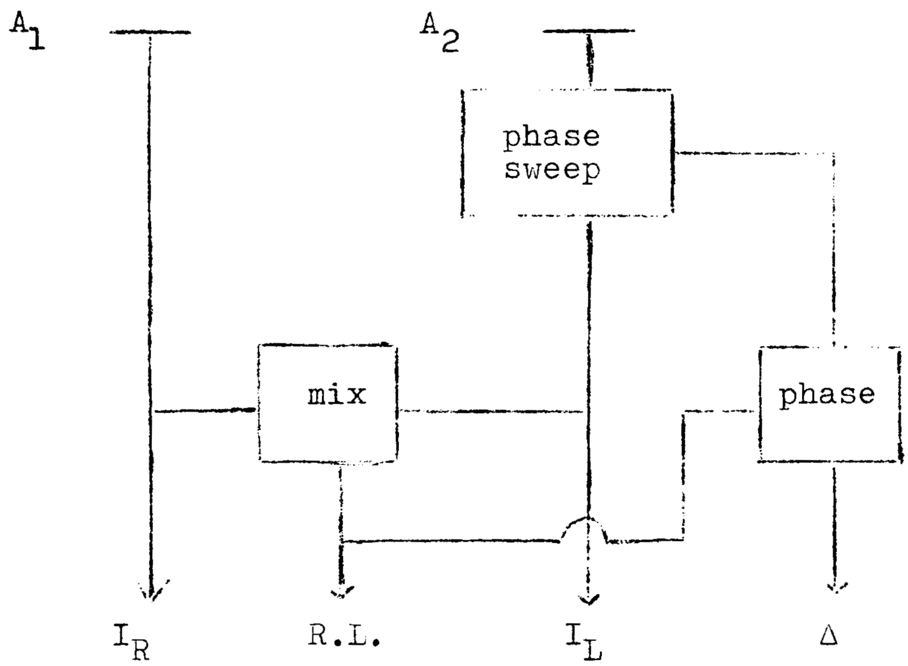


Figure 10. Schematic of the polarimeter unit.
(After Cohen (24)).

Date of M-Region Interaction with Earth	Phase Angle	Time of Interaction with Jupiter	Observed Activity
April 2	+81.1°	April 7-8	April 8 - Barrow, Douglas & Warwick
May 1	+73.8°	May 5-6	May 4 - Barrow, Douglas & Warwick May 5 - Douglas
May 24	+52.0°	May 27-28	May 26,27,28 - Warwick
June 7	+43.0°	June 9-10	June 9 - Warwick
June 20	+28.0°	June 22-23	June 22 - Barrow & Warwick June 23 - Warwick
July 4	+ 4.5°	July 4-5	July 4 - Barrow, Douglas & Warwick
August 1	- 5.6°	July 31-Aug 1	August 1 - Warwick
August 29	-32.0°	August 30-31	August 31 - Warwick

TABLE 1.

Date 1964	Trondheim	St. Osyth	Valencia	Ibadan	Grahamstown
Aug. 24	0435 - 0440 0454 - 0513	no activity reported	0428 - 0440 0452 - 0504	0420 - 0430 0444 - 0511	no observation
Oct. 5	0059 - 0151	0054 - 0155	0055 - 0147	0105 - 0116	0055 - 0150
Oct. 24	2308 - 2318 0018 - 0048	2310 - 2340 0020 - 0100	0023 - 0100	no activity reported	2305 - 2335 0023 - 0057

TABLE 3.